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Large–scale Holographic Memory: Experiment Results

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We describe a holographic optical memory capable of storing up to 10^{12} bits of information. The stored information is retrieved in blocks or pages, each consisting of $10^3 \times 10^3$ bits. Each page can be accessed randomly in approximately 100 μsec with an experimentally measured SNR of 816.8, and a projected probability of error of 10^{-28}.

A simplified schematic diagram of the entire system is shown in Figure 1. The storage medium is a slab of iron-doped $LiNbO_3$ crystal. Holograms are stored in a 16×16 array of locations on the crystal surface. Each location contains a superposition of 4,000 holograms with each hologram containing a million pixels. It has been shown that up to 5,000 high resolution holograms can be stored in a single location of $LiNbO_3$ crystal [1,2]. (An example of the reconstruction of high-resolution hologram is shown in Figure 2.) There are two crucial issues in this memory: The probability of error with which a bit can be retrieved, and the scanning mechanism that can allow us to address any one of the more than 1,000,000 holograms stored in the crystal array. In this presentation, we address these two issues and present the scanning mechanism and experimental demonstration of information retrieval with very low probability of error.

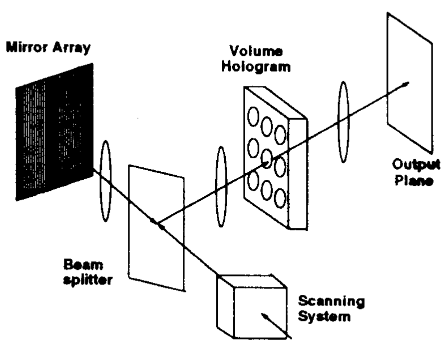

Figure 1. Mirror Array system

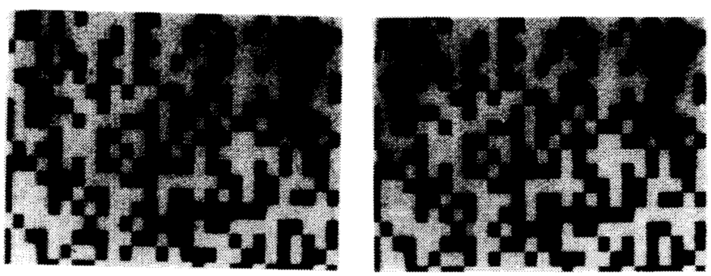

Figure 2. Image and reconstruction

Cross-talk between holograms sharing a common volume has been measured in the recording and reconstruction of 500 and 1,000 holograms [3]. In these experiments, computer–generated random–bit patterns were recorded as volume holograms within a single crystal of lithium niobate. The results are summarized as follows:

$$[\text{logic } 1]_{avg} = 2940, \qquad [\text{logic } 0]_{avg} = 0.56, \qquad \text{and} \quad \sigma_0 = 1.8,$$

where $[\text{logic } 1]_{avg}$ is the average signal level, $[\text{logic } 0]_{avg}$ is the average cross-talk level, and σ_0 is the standard deviation of the cross-talk. Assuming a gaussian distribution for the cross-talk and a threshold level halfway between $[\text{logic } 1]_{avg}$ and $[\text{logic } 0]_{avg}$, the projected probability of error was

$$P_e = Erfc\left(\frac{2,940 - 1,469.72}{1.8}\right) < 10^{-28},$$

which is far below the industrial standard of 10^{-12}.

The amount of information that can be stored at a single location is limited in practice to about 10^9–10^{10} bits. This limitation arises from the space–bandwidth product of the spatial light modulator used to enter blocks of data into the system, and the number of resolvable angles at which the reference beam can be set. Experimental semiconductor memories have been developed with capacities of 64 Mbits on a single chip. It is therefore very likely that in the foreseeable future it will be possible to construct a semiconductor memory with capacity comparable to a single location of the holographic memory with comparable size, faster access, and probably smaller cost. It is, therefore, difficult to imagine that *single location* holographic memories will be competitive enough to survive.

As the capacity of semiconductor memories grows, there will be a need for even higher capacity secondary memories. Existing disk and tape technologies, because of their relatively slow access speed, will not fulfill this need completely. Holographic memories can fill in the gap between semiconductors and disk and tape if 10^{11}-10^{12} bit holographic memories can be built at reasonable cost. Overall storage capacity of holographic memories can be increased by storing angle-multiplexed holograms in multiple locations. A non-mechanical scanning mechanism will be needed if a faster-than-disk access speed is required.

The non-mechanical scanner in Figure 1 is composed of acousto-optic devices (AODs) and a custom mirror array (Figure 3). The mirror array is composed of a stack of 256 mirror strips of different orientations. An AOD and a lens will focus light onto different mirror strips, which in turn will redirect collimated light to different locations on the storage medium with the help of another lens. If the light is focused onto different parts of a mirror strip, the redirected light will illuminate a single location on the storage medium but at different incidence angles. The mirror array can be manufactured by using traditional blazed-grating technology, and one such mirror array has been built (Figure 4).

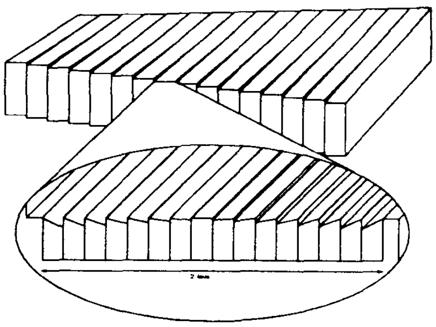

Figure 3. Mirror Array Design

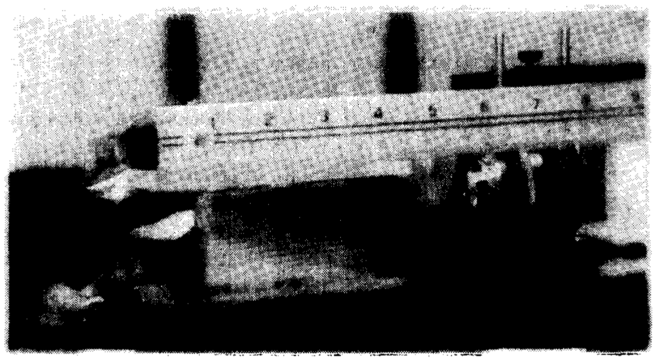

Figure 4. Mirror Array

We have experimentally demonstrated the scanning ability of the system with a setup similar to that shown in Figure 1. An f/2 lens was used to focus the beam onto the mirror array, and a beamsplitter placed behind the scanning system to direct the reflected spots onto grid paper. When the beam was scanned horizontally across the mirror array, each row of spots was traced out in turn on the grid paper—demonstrating the ability to reach separate storage locations. Four such locations out of the 130 limited by our lens aperture are shown in Figure 5. By vertically scanning the mirror array, we can produce different reference angles at the same location, allowing multiple storage of holograms.

Figure 5. Experimental demonstration of multiple location scanning

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References

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